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Timing and Duration of Subsidence Due to Longwall Mining

UNITED STATES DEPARTMENT OF THE INTERIOR



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Timing and Duration of Subsidence Due to Longwall Mining

By Paul W. Jeran and Michael A. Trevits

**UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary**

**BUREAU OF MINES
Rhea Lydia Graham, Director**

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

m	meter	mm/m	millimeter per minute
m/d	meter per day	pct	percent

U. S. Customary Units

ft	foot	ft/d	foot per day
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TIMING AND DURATION OF SUBSIDENCE DUE TO LONGWALL MINING

By Paul W. Jeran¹ and Michael A. Trevits²

ABSTRACT

Subsidence data gathered by the U.S. Bureau of Mines over a series of longwall panels in the Pittsburgh Coalbed were studied to obtain insight as to the role of time in the subsidence process. It was found that subsidence began essentially with undermining and was completed within 1 year. The progress of the subsidence was dependent upon location above the panel. Subsidence in the central area of the subsidence trough, where subsidence is the greatest, was about 90 pct complete by the time the face had progressed a distance equal to one overburden thickness beyond a particular surface point. For a point over the rib of the longwall panel, the subsidence was only about 60 pct complete at this time. Data from three other sites in the northern Appalachian Coal Basin were analyzed to determine if an anomaly or the true characteristics of the subsidence process had been observed. All sites behaved similarly in the central portion of the subsidence trough. However, the subsidence of points over and adjacent to the ribs of the longwall panels was site specific. The fact that movement across the width of the panel was not uniform should be taken into account in assessing damages or the potential for damages resulting from mining-induced subsidence.

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INTRODUCTION

The mining of a large rectangular block of coal by the longwall method results in the development of a trough-shaped depression of the surface above the extracted area. The process of subsidence is dynamic, as surface movement begins with undermining and continues until some maximum displacement has occurred; the magnitude of the displacement is controlled primarily by the thickness of the extraction, the width of the panel, and the overburden thickness and geology. At the end of the subsidence process, equilibrium is achieved and the resulting surface deformations become static. Any subsequent movement of the surface results not from subsidence but from the altering of the conditions affecting the rock strata disturbed by subsidence (e.g., injection or removal of fluids, erection of structures).

During any discussion of potential subsidence with longwall mine operators and particularly with surface property owners, several questions always arise: How much subsidence will occur? What will be affected? When will subsidence begin? How long will the process of subsidence last? Answers to the first two questions can be estimated using the geometry of mining as input into the U.S. Bureau of Mines (USBM) subsidence prediction model for the northern Appalachian Coal Field (1).³ The latter two questions are the subject of this report.

Subsidence monitoring is typically carried out in two directions: along the centerline of the panel to obtain data that will show the maximum amount of subsidence and the duration of the dynamic phase of movement and across the panel (perpendicular to the centerline) to evaluate the lateral extent of surface deformations, the final cross section of the developed subsidence trough, and

the distribution of final deformations. These are the static result of the subsidence process, and any further movement must be attributed to some other cause.

Subsidence prediction is typically limited to the final shape of the subsidence trough. Practically all predictive models address this aspect of mining-induced ground movement.

Study of subsidence data gathered along the centerlines of a number of longwall panels in the northern Appalachian Coal Basin, by Adamek and Jeran (2), has shown that the subsidence process starts with the undermining of a surface point and is 90 pct completed by the time the longwall face has been advanced a distance equal to the thickness of the overburden beyond that point. Adamek and Jeran determined that the speed with which the face is advanced has no effect on the magnitude of surface deformations, the final movement is usually achieved with mining of the adjacent panel, and the magnitude of surface deformations that occur during dynamic subsidence is always less than the magnitude of the static case (2).

Examination of manmade features on the surface has shown that they are affected by the forces applied to them throughout the subsidence process. Therefore, the final static shape of the subsidence trough cannot be used to fully explain the degradation of the surface features or how they came to their final condition. It has also been observed that the degree of degradation is dependent upon location within the subsidence trough (3).

This report presents results from continuing studies on subsidence, in particular on its timing and duration. This work is in support of the USBM mission to mitigate the environmental impacts of mining.

FIELD STUDIES

Long-Term Study

As has been noted above, the description of dynamic subsidence has been limited to movement along the centerline. However, does this behavior occur equally across the developing subsidence trough? To obtain some insight into this question, long-term subsidence data were needed. At one site in northern West Virginia, the USBM monitored a series of longwall panels in the Pittsburgh Coalbed, remote from previous high-extraction mining. Monitoring was conducted for over 2 years, during which time four

adjacent longwall panels were mined. Surface monuments were installed over the first three panels (figure 1), and monitoring was conducted over the portions of the array that were actively moving because of undermining. Periodic measurements were also made of the priorly undermined portions of the array to determine final movement. Above the first two panels, no further vertical movement was detected after the subsequent adjacent panel was mined (4).

To simplify the analysis, four monuments across the first panel, as shown in figure 1, were selected: A, above the centerline, B, 30.48 m (100 ft) from the centerline, C, 30.48 m (100 ft) inside the rib abutting the barrier pillar,

³Italic numbers in parentheses refer to items in the list of references at the end of this report.

and *D*, above the rib abutting the barrier pillar. Figure 2 shows a plot of the subsidence of these four monuments versus time. Also included are the face positions showing the progress of mining for the studied panels. The last measurement was made after mining of the fourth panel was completed. Each face position line indicates the location of each face during the study. From this, we can see that each monument experienced most of its movement with the mining of panel 1 and had completed movement with the mining of panel 2. Figure 3 shows the first 60 days of the study. From this, it can be observed that the monuments were undermined on the 25th day and some minor movement had been detected as much as 10 days earlier. Furthermore, most movement occurred within 30 days after undermining.

Since each monument subsided a different amount, the percentage of final movement for each measurement was computed to provide some basis of comparison. Negative values of time and face position, where they occur on graphs, indicate data acquired prior to undermining of the monuments. When the percentages of final subsidence are plotted against face position (figure 4), it can be seen that the three interior monuments (*A*, *B*, and *C*) subsided more than 85 pct of their final movement by the time the face was 245.44 m (800 ft) past the monument line. Movement of the monument over the rib (*D*) was only 70 pct complete at this time. Plotting the percentage of final subsidence against time (figure 5) shows that all of the monuments behaved similarly for the first 10 days after undermining. After that period, the two central monuments (*A* and *B*) behaved similarly and the behavior of the monument 30.48 m (100 ft) inside the rib (*C*) lagged slightly behind. The rib monument (*D*) behaved differently.

From the above, it can be concluded that subsidence of the monuments within the panel limits is governed by face position and time. Subsidence of the monument over the rib, after its initial movement, is governed more by time.

Short-Term Studies

Since these observations represent information from only one site, other sites, with shorter durations of study, were investigated to confirm or deny our observations.

Three mine sites were selected, one in each of three coalbeds: Pittsburgh, Lower Kittanning, and Freeport. Figure 6 shows the locations of these sites, and table 1 contains data describing the panel width, overburden thickness, average rate of face advance, and coalbed for the sites. Mine A is the site of the original, long-term study. The Pittsburgh Coalbed site, mine B, was chosen to determine if the observations were limited to operations in this coalbed (the original site was in the Pittsburgh Coalbed). Overburdens, extracted thicknesses, rates of face advance and geometries varied among the sites. Figure 7 is a plot of face advance for each of the sites. The average rates of mining ranged from 3.05 m/d (10.0 ft/d) at mine B to 11.83 m/d (38.8 ft/d) at mine D.

In all cases, the monuments chosen were from the profile line extending from the centerline outward, away from subsequently mined panels. Since the extracted thicknesses were different, which resulted in differing magnitudes of subsidence, the percentage of the final movement of each monument was calculated and used in the comparisons. It should be noted that the process of subsidence at all sites was completed within 1 year of undermining.

Data from the centerline monuments at each of the four sites plotted against time (figure 8) show that subsidence at mines C and D generally agreed with that at mine A, while at mine B subsidence was much slower. Mine B had the slowest face advance and greatest overburden thickness. Considering that dynamic subsidence is proportional to face advance and inversely proportional to overburden thickness (2), a slower rate of subsidence for mine B could be the expected result. When the percentage of final subsidence was plotted against face position (figure 9), mines A and B (Pittsburgh Coalbed) were in agreement, with mines C and D differing. It should be noted, however, that mines C and D had lesser overburden thicknesses. When plotted against face position in terms of overburden thickness (figure 10), all sites were in closer agreement. Note, in figure 10, for the centerline monuments, subsidence at all sites was about 90 pct complete when the face had advanced the thickness of the overburden beyond the monument location. These observations agree with the findings of the earlier study by Adamek and Jeran (2).

Table 1.—Study sites information

Mine	Panel width		Overburden		Average face advance		Coalbed
	m	ft	m	ft	m/d	ft/d	
A	190.5	625	210.3-213.4	690-700	6.55	21.5	Pittsburgh.
B	182.9	600	277.4-298.7	910-980	3.05	10.0	Pittsburgh.
C	289.6	950	118.9-126.5	390-415	4.94	16.2	Kittanning.
D	182.9	600	143.3-155.4	470-510	11.83	38.8	Freeport.

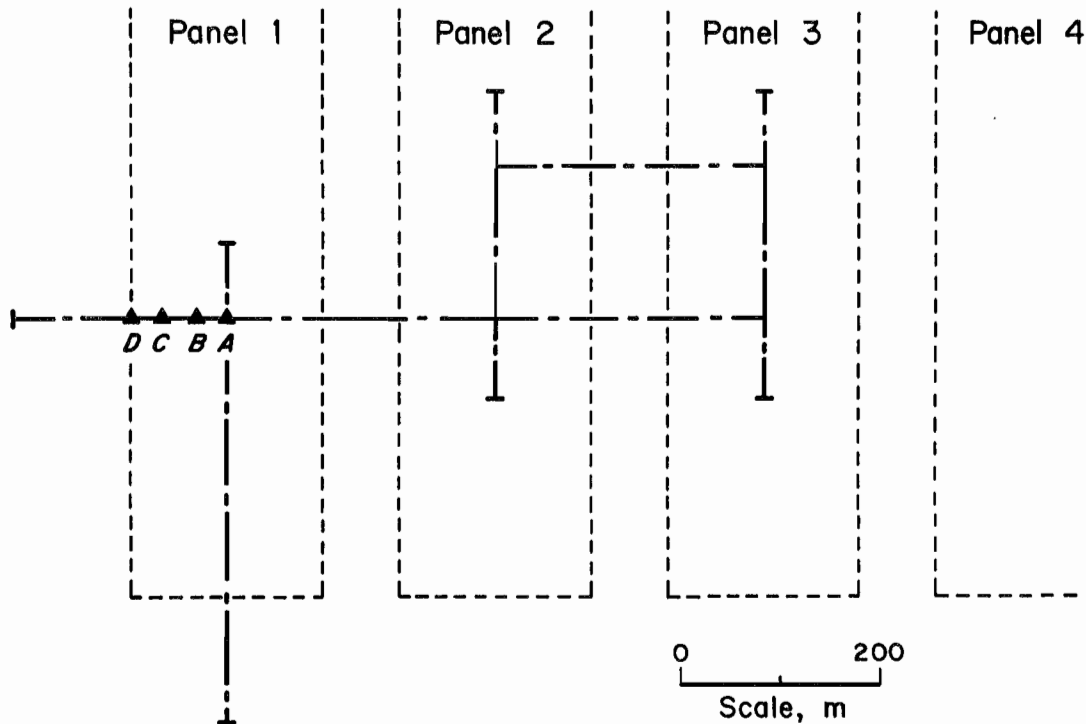
The same plots were made for the monuments 30.48 m (100 ft) from the centerline for the four sites under study (figures 11-13). Again, as for the centerline points, the plot of subsidence versus face position in terms of overburden thickness shows the closest agreement, and again, over 90 pct of the final subsidence was completed when the face had advanced the thickness of the overburden past each point.

Plots for subsidence at the monuments 30.48 m (100 ft) inside the rib versus time and face position (figures 14-15) are similar to those for the more centrally located monuments. However, the plot of the percentage of final subsidence versus face position-overburden ratio (figure 16) shows that this location at mine D lagged behind the same location at the other three mines, indicating retardation of the subsidence process. The overburden at this site

contains significantly more and thicker sandstone units. These stiffer members bridge farther over the gob than the less resistant strata at the other sites. Additional time is needed for the stiffer units to bend into the gob area.

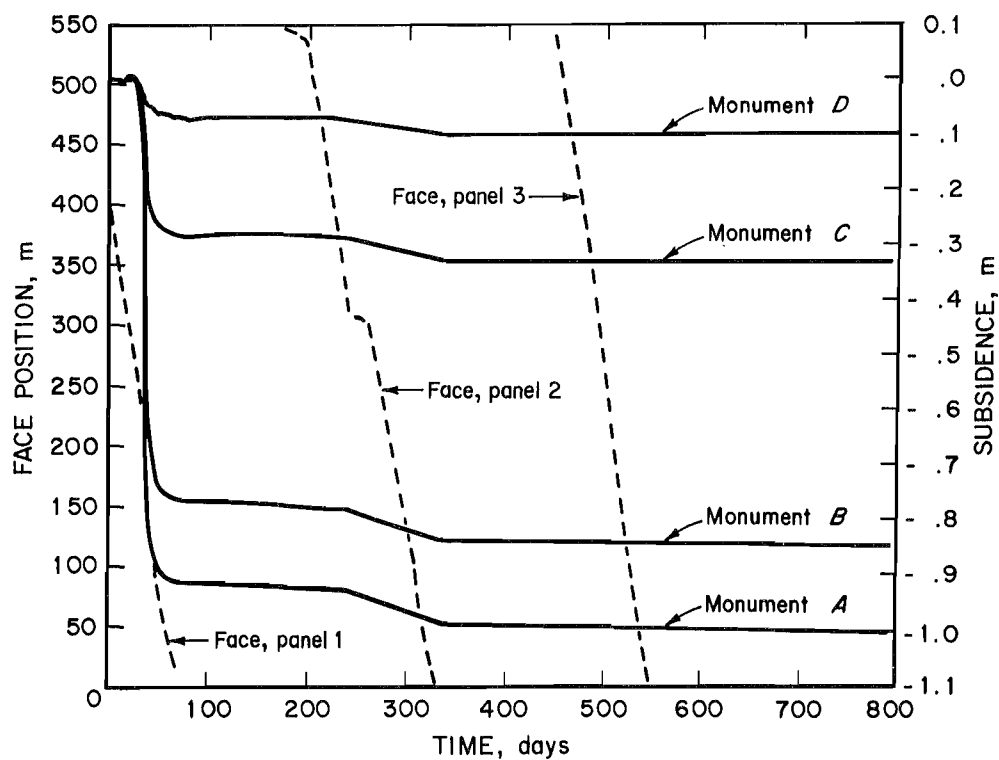
The similar plots for the rib monuments (figures 17-19) show a different characteristic. Plots of the percentage of final subsidence versus face position (figure 18) and face position in terms of overburden thickness (figure 19) do not show the same trends as observed for subsidence at the other points. The plot of percentage of final subsidence versus time (figure 17), however, shows that within a month of undermining, these monuments had completed from 40 to 70 pct of their final subsidence. This indicates that the process of subsidence over the rib is very much site dependent and time appears to play a very significant role.

Figure 1



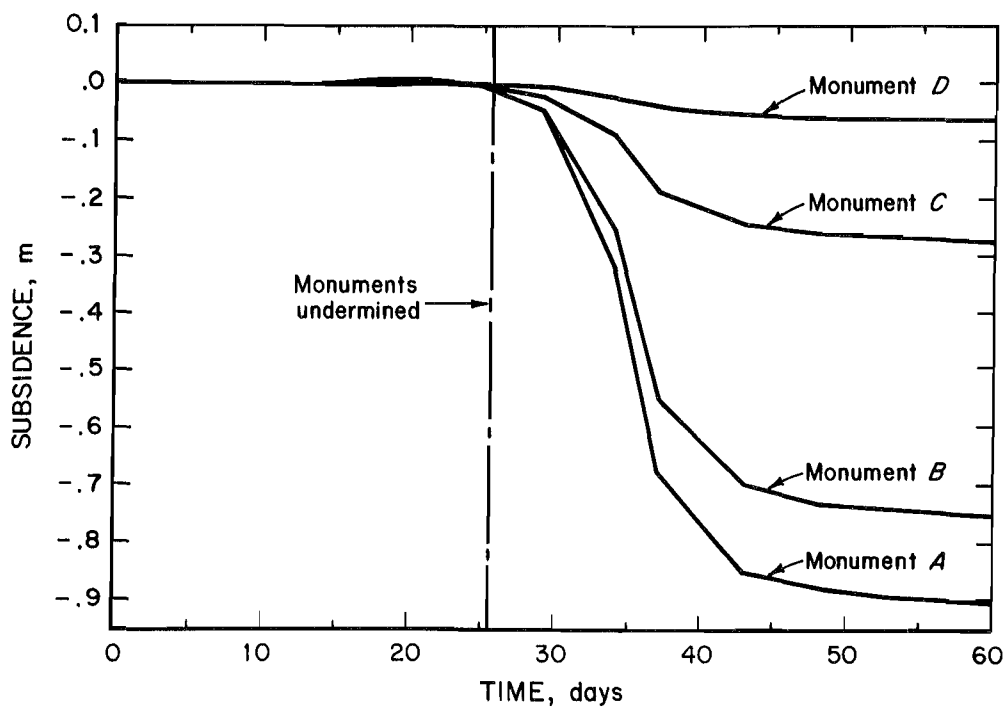
Monitoring array. A, B, C, and D are monuments.

Figure 2



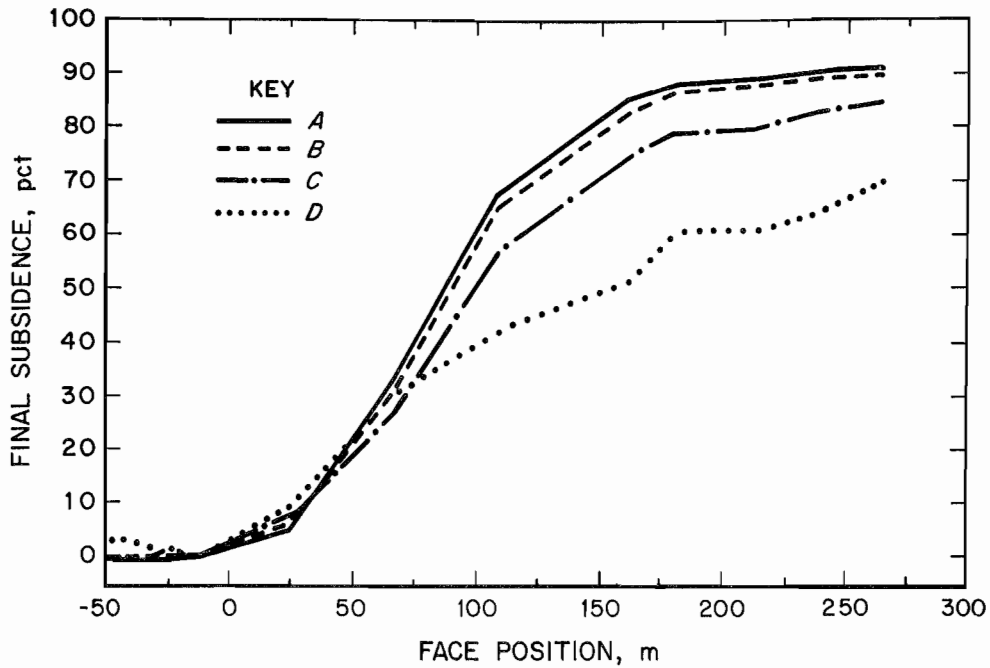
Subsidence during long-term study versus time.

Figure 3



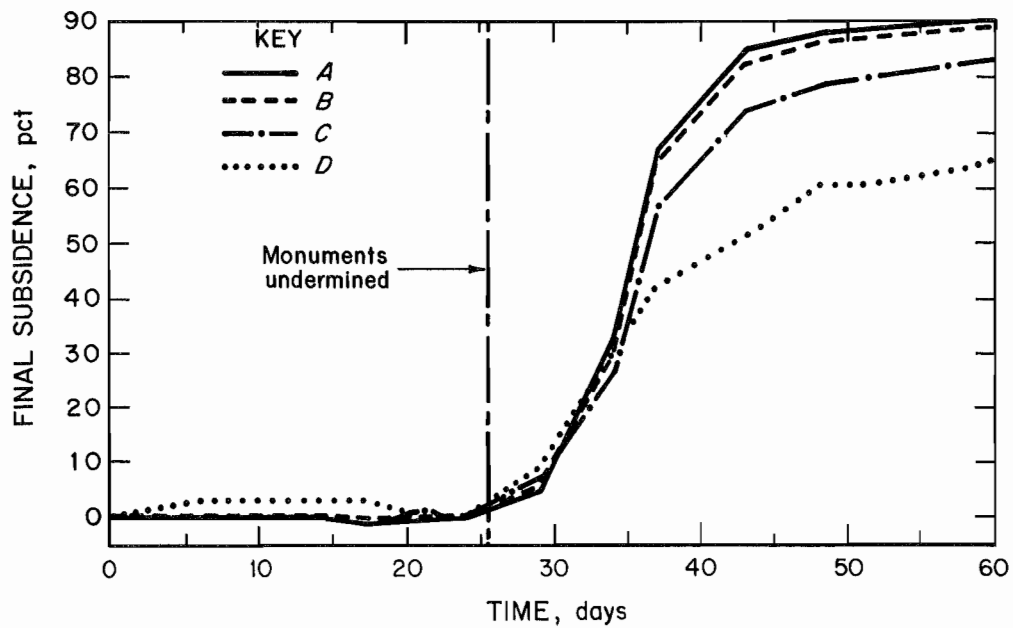
Subsidence during first 60 days.

Figure 4



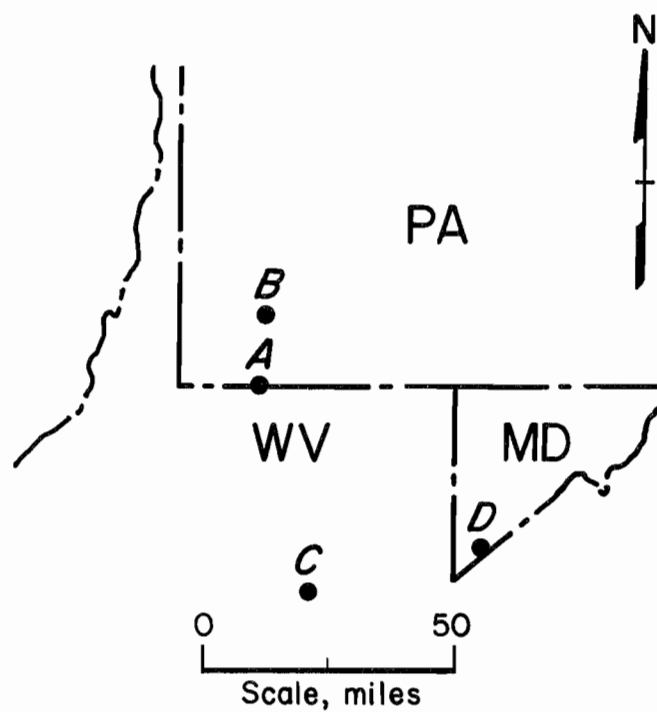
Final subsidence versus face position.

Figure 5



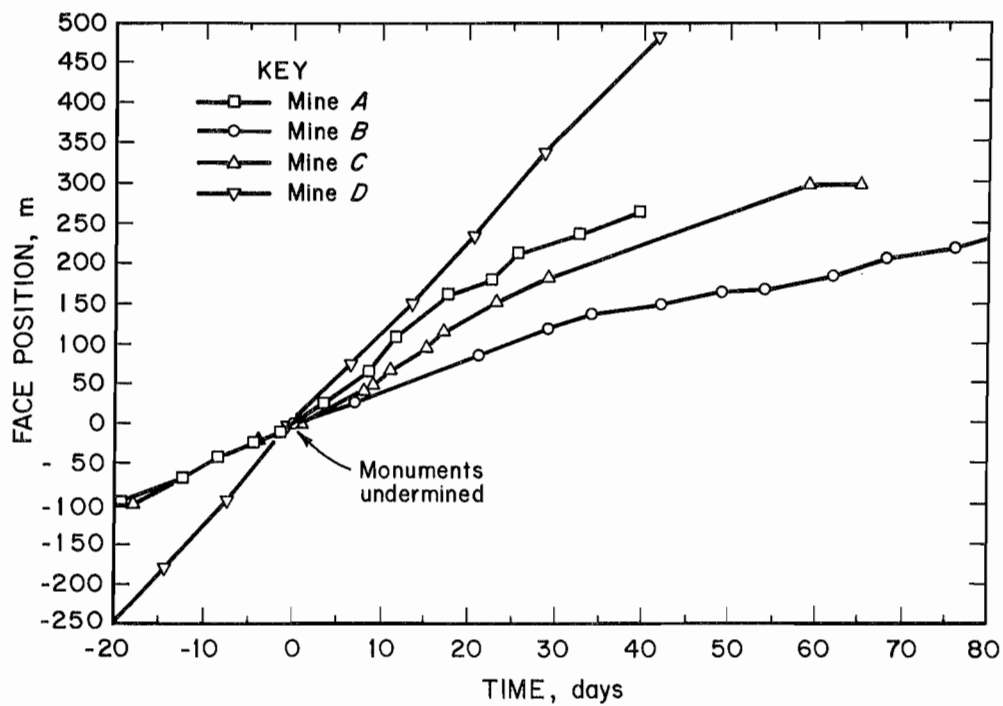
Final subsidence versus time.

Figure 6



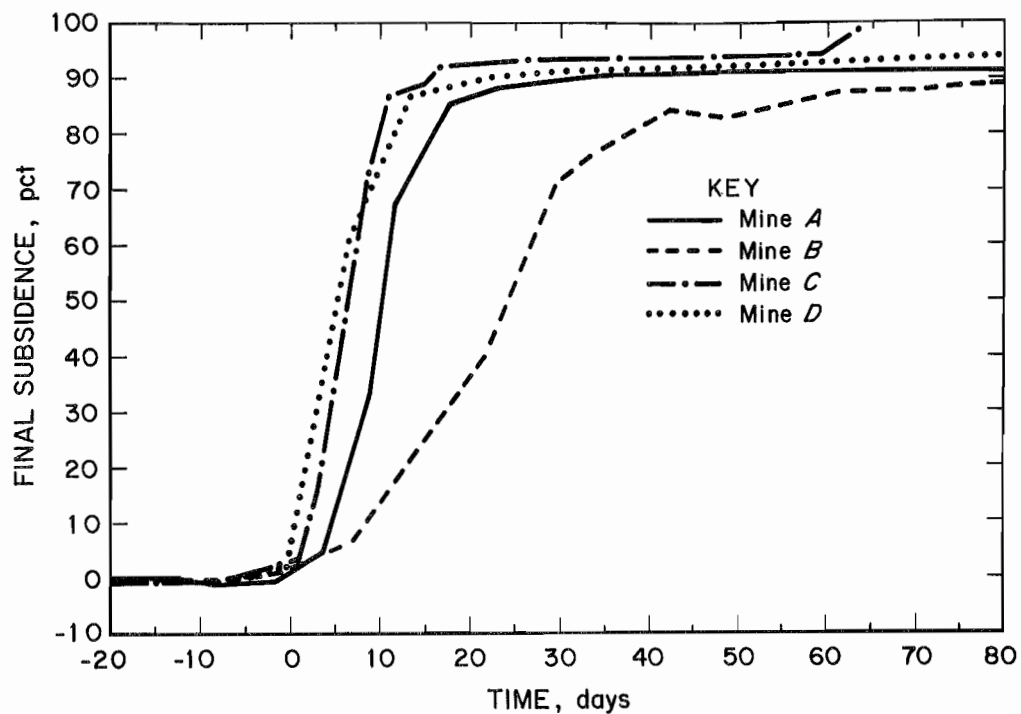
Location of mines.

Figure 7



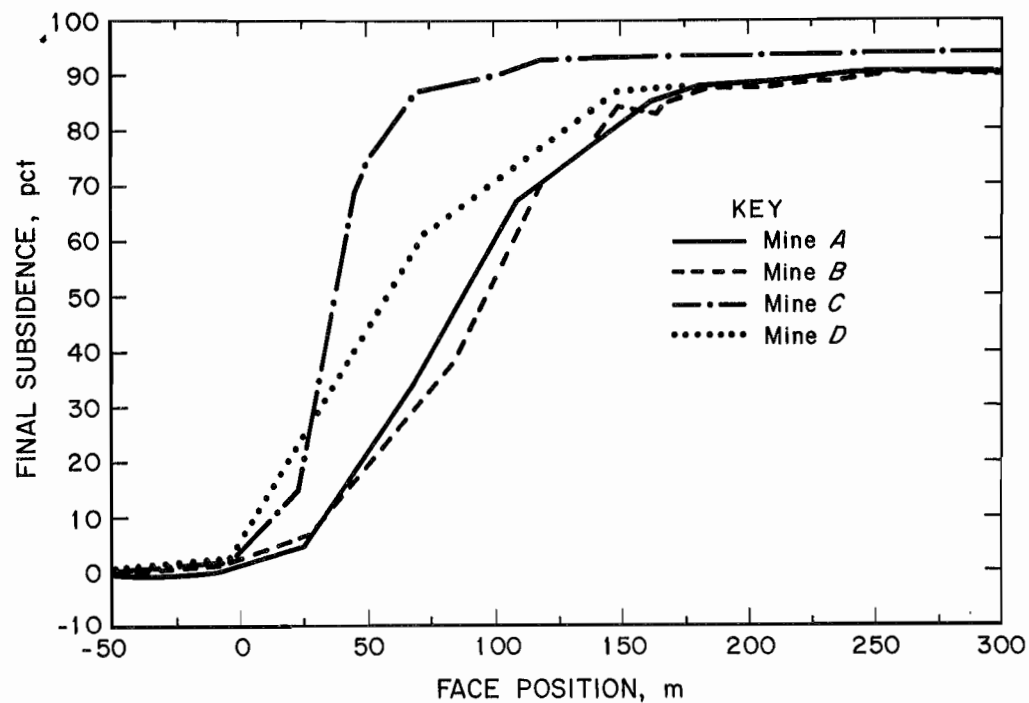
Face advances.

Figure 8



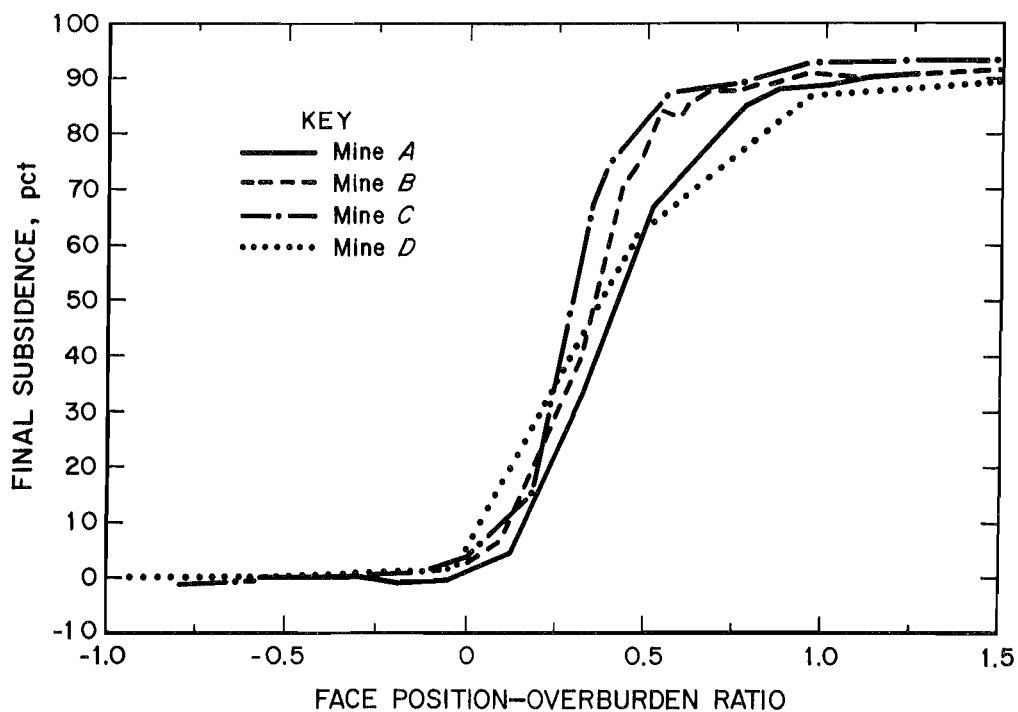
Subsidence at centerline points versus time.

Figure 9



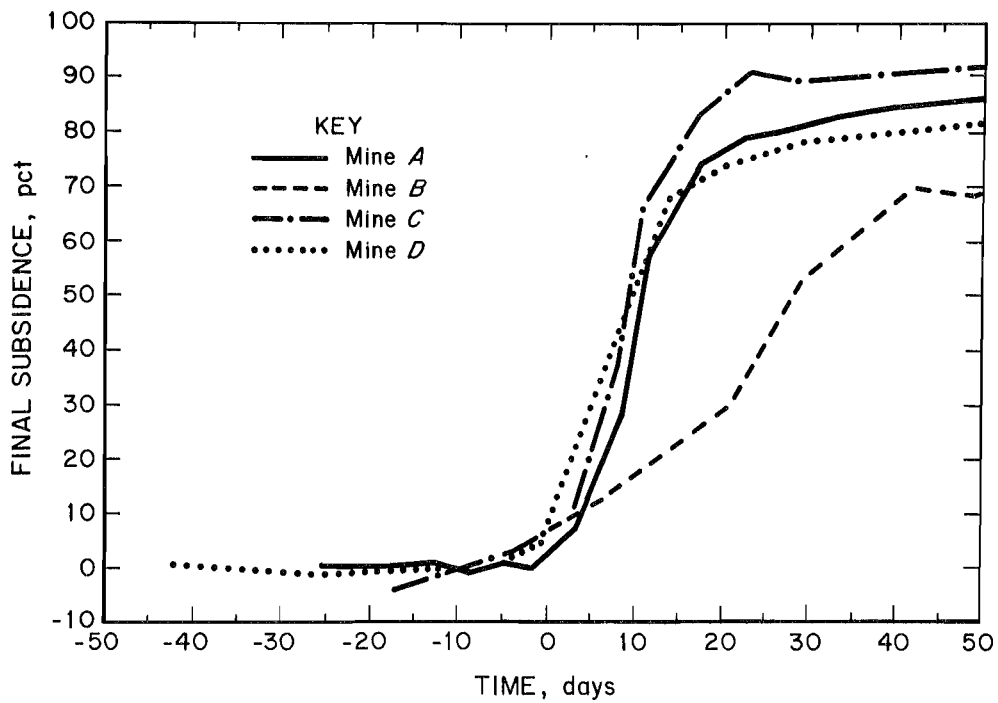
Subsidence at centerline points versus face position.

Figure 10



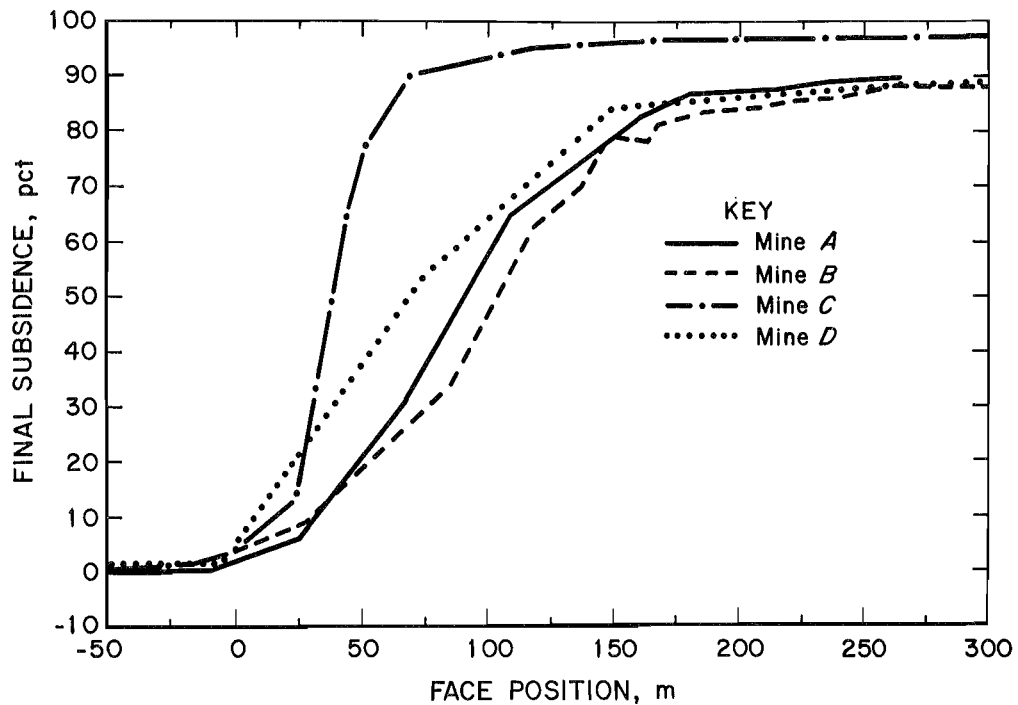
Subsidence at centerline points versus face position-overburden ratio.

Figure 11



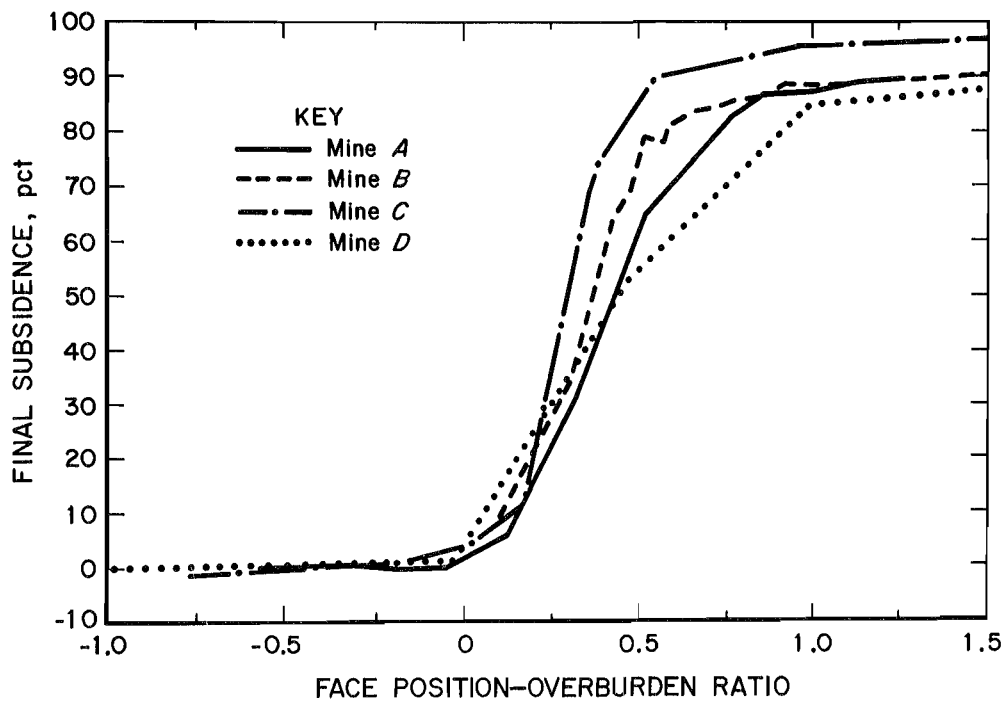
Subsidence 30.48 m from centerline versus time.

Figure 12



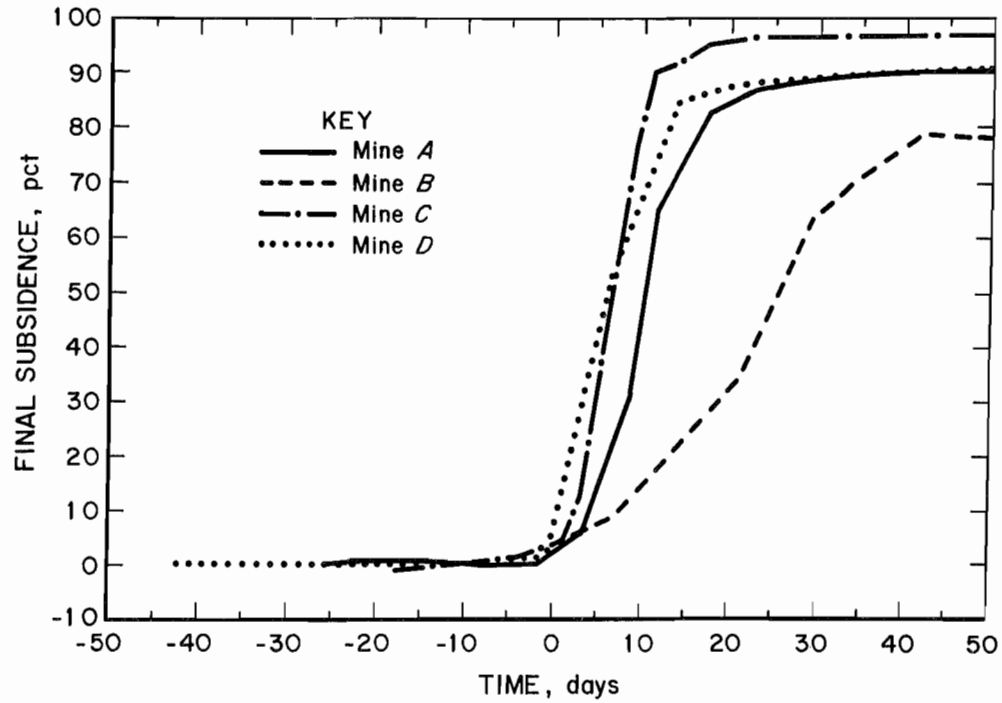
Subsidence 30.48 m from centerline versus face position.

Figure 13



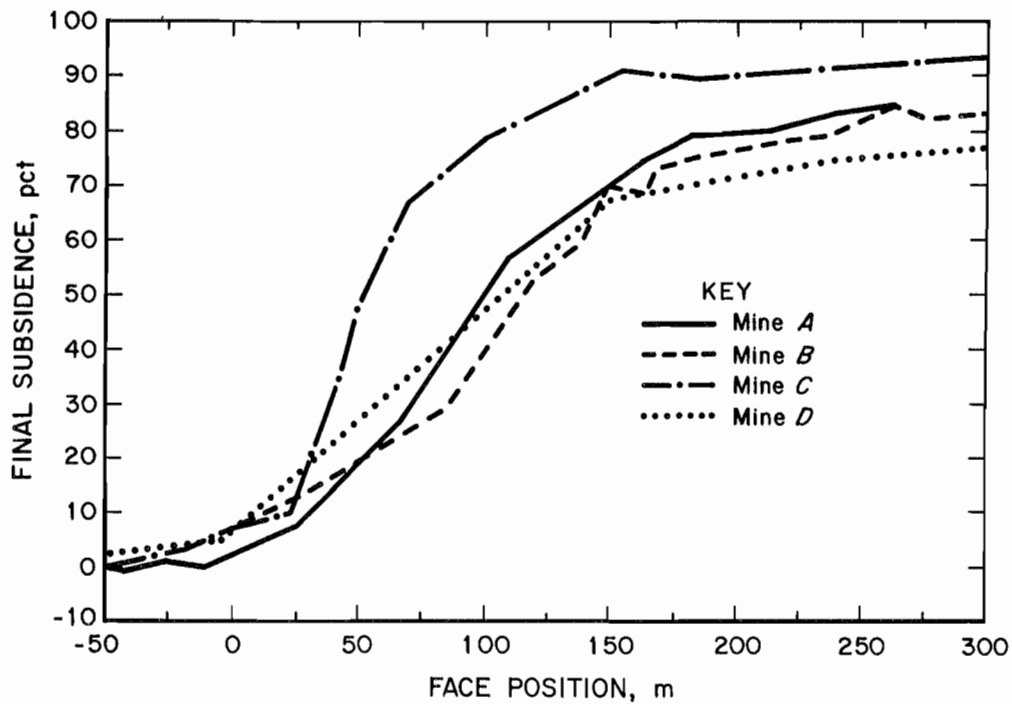
Subsidence 30.48 m from centerline versus face position-overburden ratio.

Figure 14



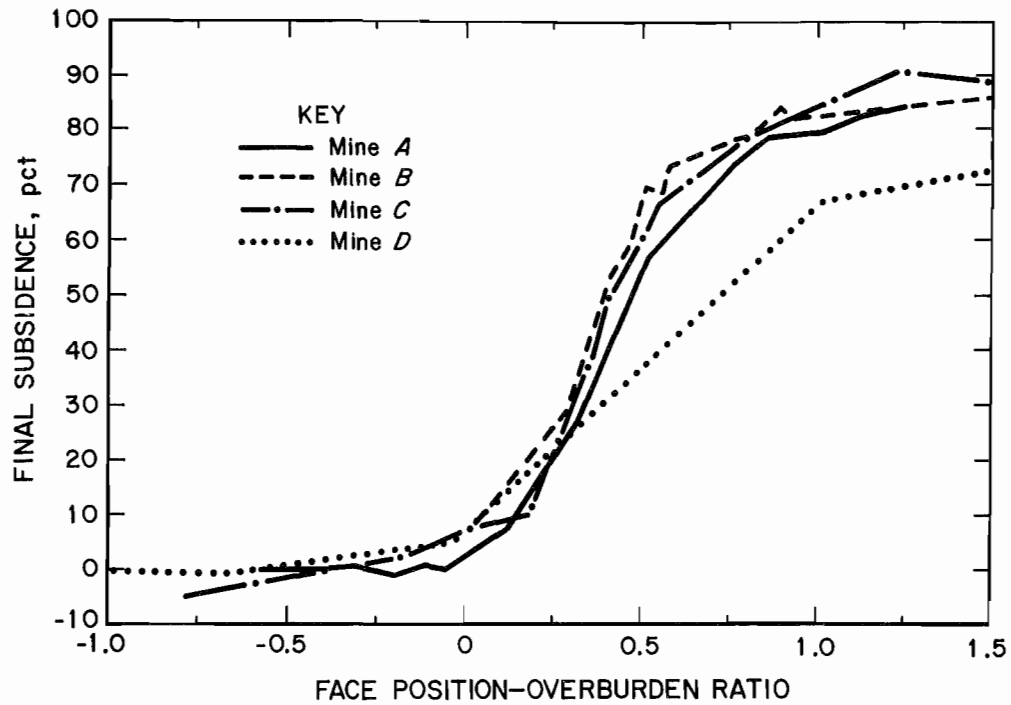
Subsidence 30.48 m inside rib versus time.

Figure 15



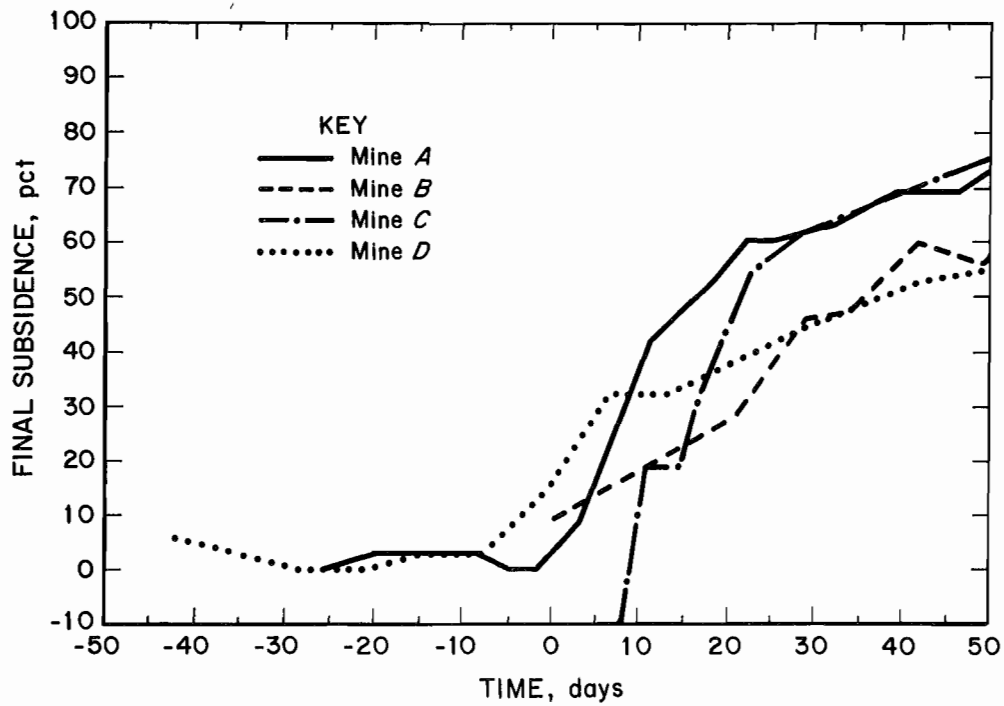
Subsidence 30.48 m inside rib versus face position.

Figure 16



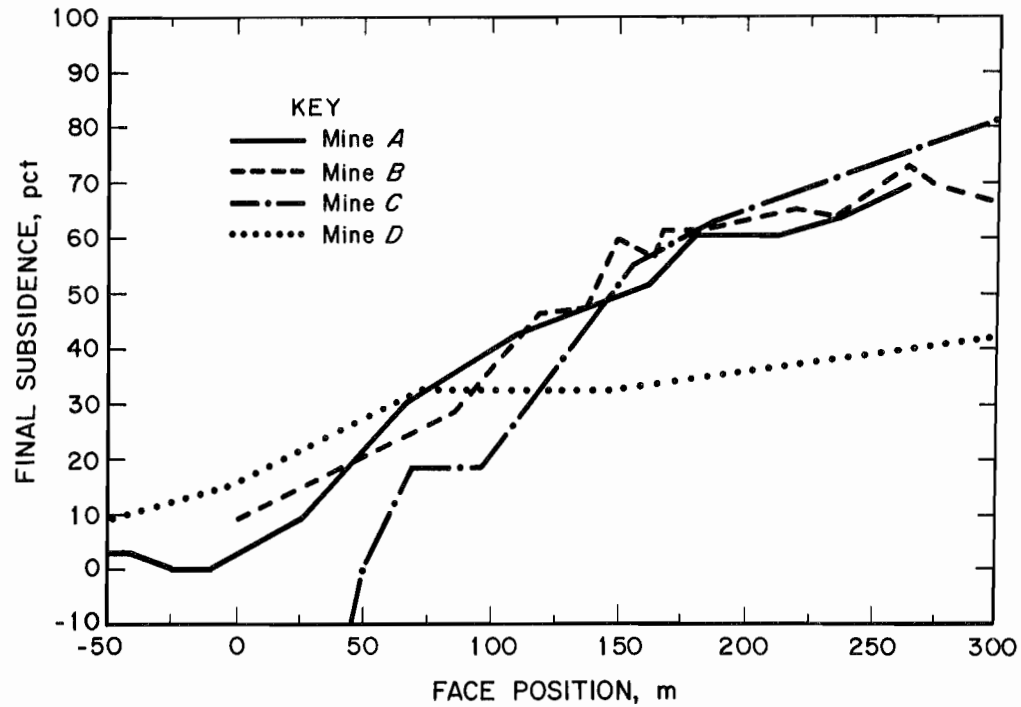
Subsidence 30.48 m inside rib versus face position-overburden ratio.

Figure 17



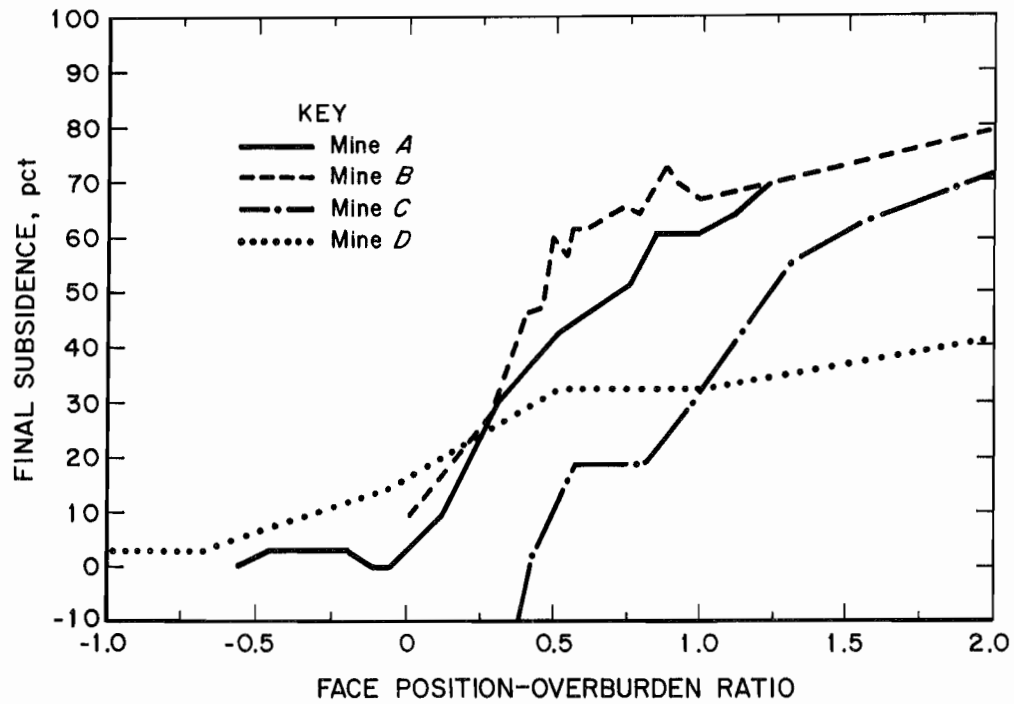
Subsidence at rib points versus time.

Figure 18



Subsidence at rib points versus face position.

Figure 19



Subsidence at rib points versus face position-overburden ratio.

DEFORMATIONS

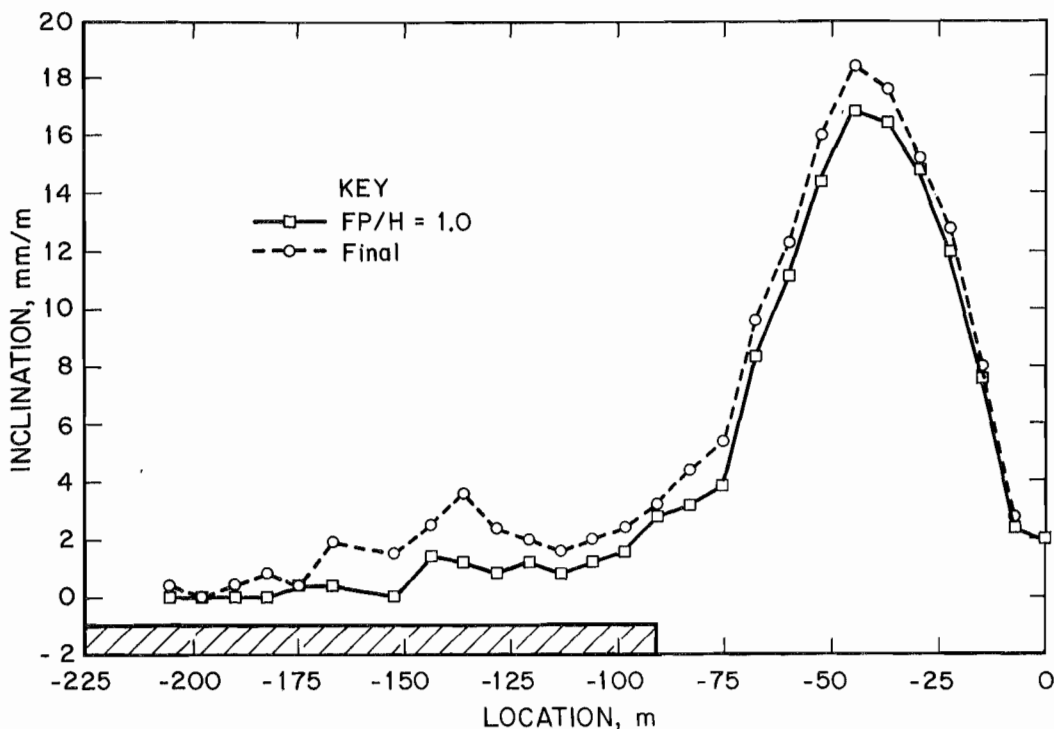
Underlying all discussions of subsidence resulting from longwall mining is the concern for damages. From the above discussion it can be seen that, except for the area above the rib, most of the surface movement is accomplished by the time that the longwall face has been mined past the thickness of the local overburden. It is logical to assume that most of the deformations of the surface are also completed by this time.

The study of dynamic subsidence (2) showed that the magnitudes of dynamic deformations (inclination, curvature, and horizontal strain) are always less than the static values. Therefore, if the differences between the values of final static deformations and those developed at the time the longwall face has been mined one overburden thickness past the profile are small, then additional dynamic deformations should also be small.

The distribution of static inclinations was calculated for each of the profiles used in this study at the point where

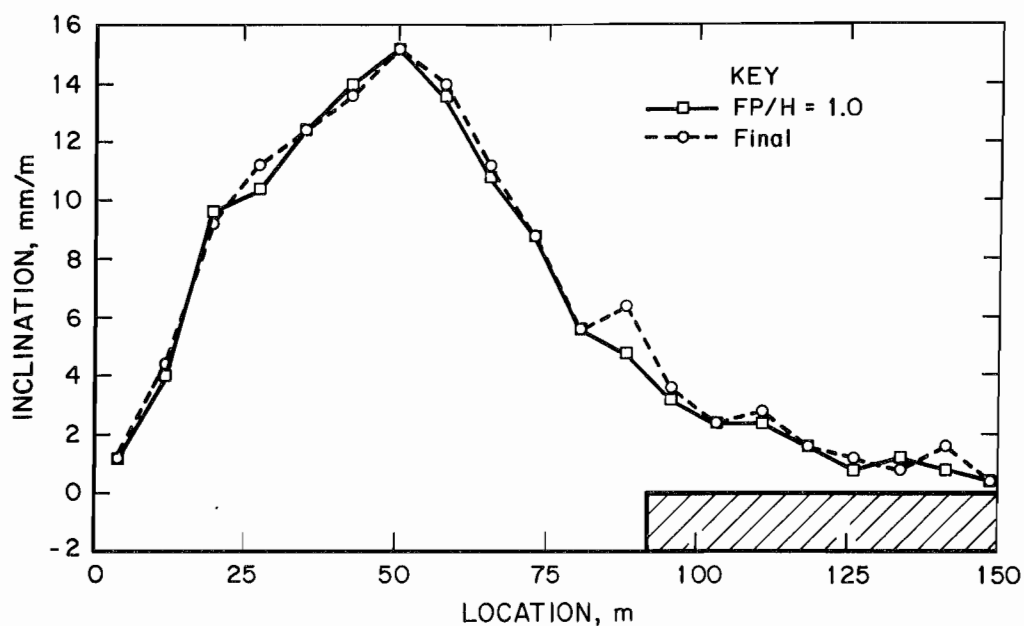
the longwall face had been mined one overburden thickness past and again when subsidence had been completed. These distributions are shown in figures 20 through 23. They show that static inclinations increased by less than 3 mm/m. Therefore, any change in dynamic inclinations should be smaller than these values. From these we must conclude that, for these sites, the surface deformations occurred primarily during the mining of the longwall face one overburden thickness past the profile. Additional deformations were small. Since there are no criteria established in this country correlating magnitude of deformation with structural damage it is impossible to state that no additional damages would result from the additional deformation. However, if criteria developed in Europe (5) are any indication, then these additional deformations should not significantly contribute to surface damages.

Figure 20



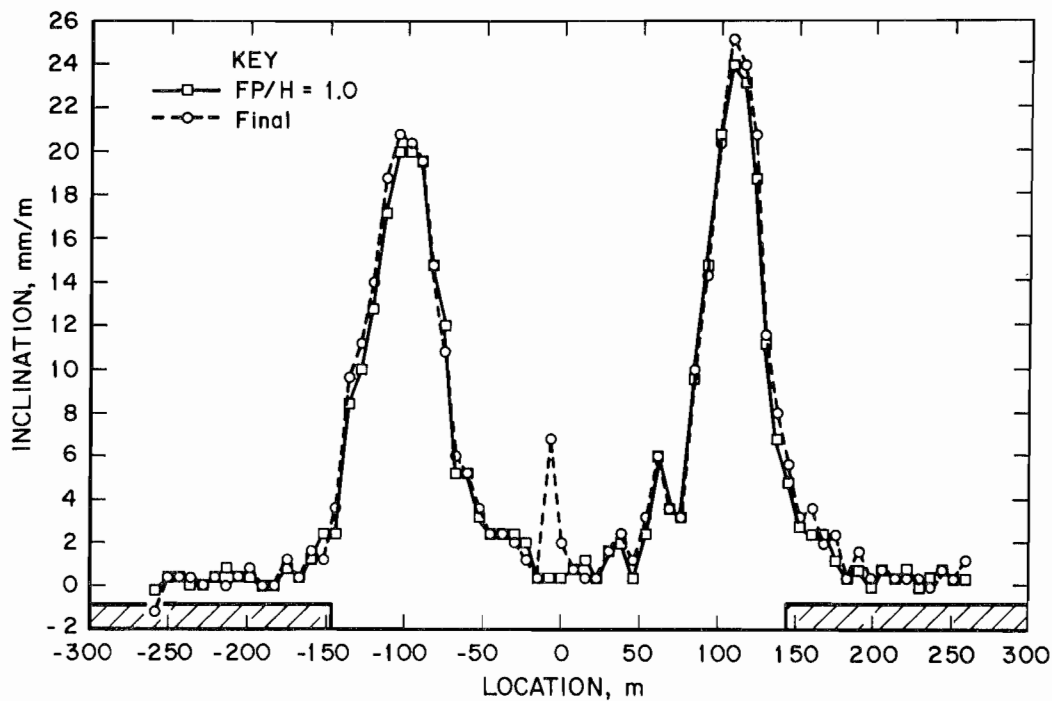
Inclination difference at mine A. (FP/H = face position-overburden ratio.)

Figure 21



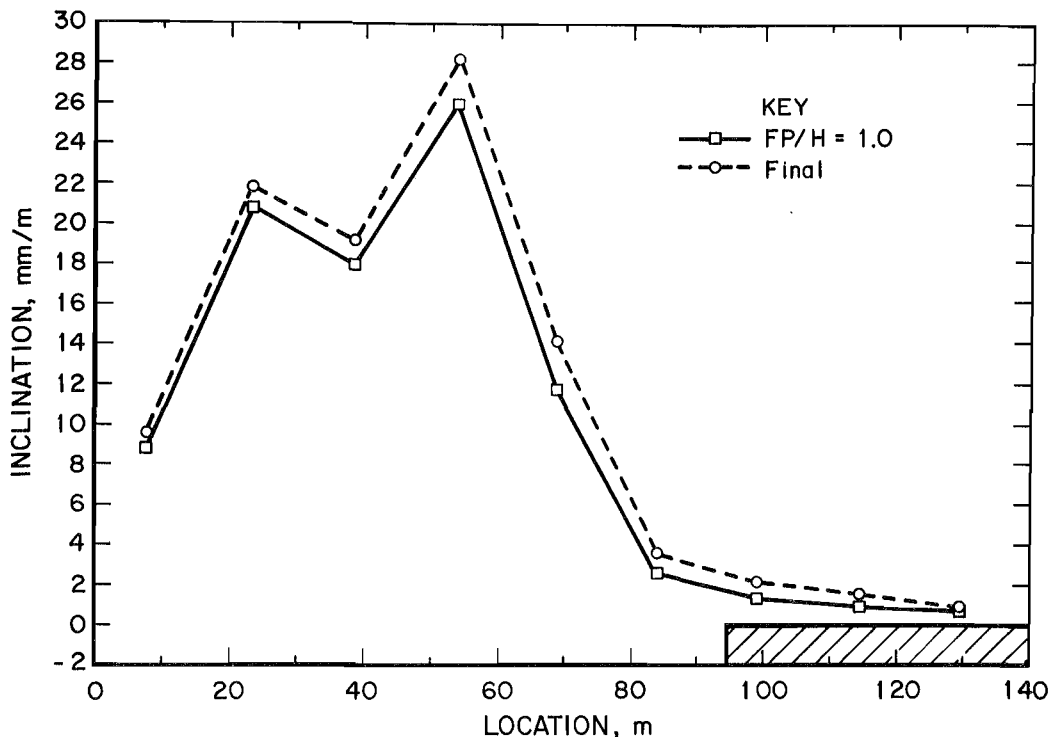
Incline difference at mine B. (FP/H = face position-overburden ratio.)

Figure 22



Incline difference at mine C. (FP/H = face position-overburden ratio.)

Figure 23



Inclination difference at mine D. (FP/H = face position-overburden ratio.)

SUMMARY

Subsidence data from four sites in the northern Appalachian Coal Basin were studied. These data show that for locations in the central portion of the developing subsidence trough (within 30.48 m (100 ft) of the centerline) subsidence develops relative to face position and overburden thickness and is about 90 pct complete when the face has advanced the thickness of the overburden beyond the point in question. Above the rib of the panel the process of subsidence is very much site dependent and time appears to play a significant role, in that when the face has advanced the thickness of the overburden past a monument only 40 to 70 pct of the movement has taken place. The remainder of the surface movement, irrespective of location above the longwall panel, takes up to a year to complete.

The monuments 30.48 m (100 ft) inside the rib exhibited movements that were characteristically between those

of the centerline and rib area monuments. With slow to moderate face advance (3.05 to 6.55 m/d), the subsidence process was similar to that over the central portion of the panel, with over 80 pct of the final movement completed when the face had advanced the thickness of the overburden past a monument. However, with fast face advance (11.83 m/d), there appeared to be some retardation or lag in the subsidence process.

At the sites studied, the preponderance of the surface deformations had occurred by the time that the longwall face had been mined one overburden thickness past each profile. The additional deformations were small. All of these factors should be taken into account in assessing damages or the potential for damages resulting from mining-induced subsidence.

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